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MINERALOGICAL STUDY OF THE NON-CLAY FRACTION IN THE BAUXITE AND THE ASSOCIATED ROCKS OF AZAD KASHMIR

K. A. MALLICK and M. VALIULLAH

ABSTRACT

Bauxite and the associated rocks from seven different localities of Muzaffarabad and Kotli areas of Azad Kashmir have been investigated for their non-clay mineral correspondence.

Rocks in contact with the bauxite are the fire clay at the base and Eocene shale at the top. The fire clay overlies the Muzaffarabad Formation of Permo-Carboniferous age.

The bauxite and the fire clay correspond closely with each other in their mineralogical composition. No relationship could be found between the top of Muzaffarabad Formation and the bottom of the fire clay.

The study reveals similar provenance and cycle of deposition for the fire clay and the bauxite with some breaks and changes when the pisolites of the bauxite were being formed.

INTRODUCTION

This paper deals with the mineralogical study of the bauxite deposits and the associated rocks in Azad Kashmir. Attempt has been made to reconstruct the depositional and post-depositional environments of the bauxite. This study also seeks to ascertion the degree of correspondence between the composition of bauxite and that of the associated rocks.

Besides the study of the physical properties, field relationships and structural continuity of the bauxite deposits and the associated rocks, a qualitative study of non-clay minerals was made to determine the mineralogical correspondence. Effort has also been made to trace the possible provenance of the fire clay and the bauxite.

GENERAL GEOLOGY

Reference to the geology of this region is found in the reconnaissance geological reports since 1879, but no attention was paid to the mineralogical study of the bauxite deposits and the associated rocks. Similarly as yet no information is available on the genesis of the bauxite or any other deposits of the area.

The bauxite and the associated rocks described in this paper are from Batmong and Khilla of Muzaffarabad area and Sawer Gunimalni, Khander, Kamroti, Nikial, and Salhun of Kotli Tehsil in Azad Kashmir territory *(Fig. 1* and *2)*. The rocks of this area comprise of Muzaffarabad Formation, Bauxite and Fire clays, Chhalpani Formation, Murree Group, Siwaliks and Alluviums of Permo-Carboniferous, Post Permian, Eocene, Middle Miocene, Pleistocene to Pliocene and Recent to Sub-Recent ages respectively.

Muzaffarabad Formation consists of limestone, dolomite and precipitation breccia. The limestone is thinly bedded, light gray to mottled gray and white in color, fine grained, hard and partly dolomitic. Joint and fractures are common.

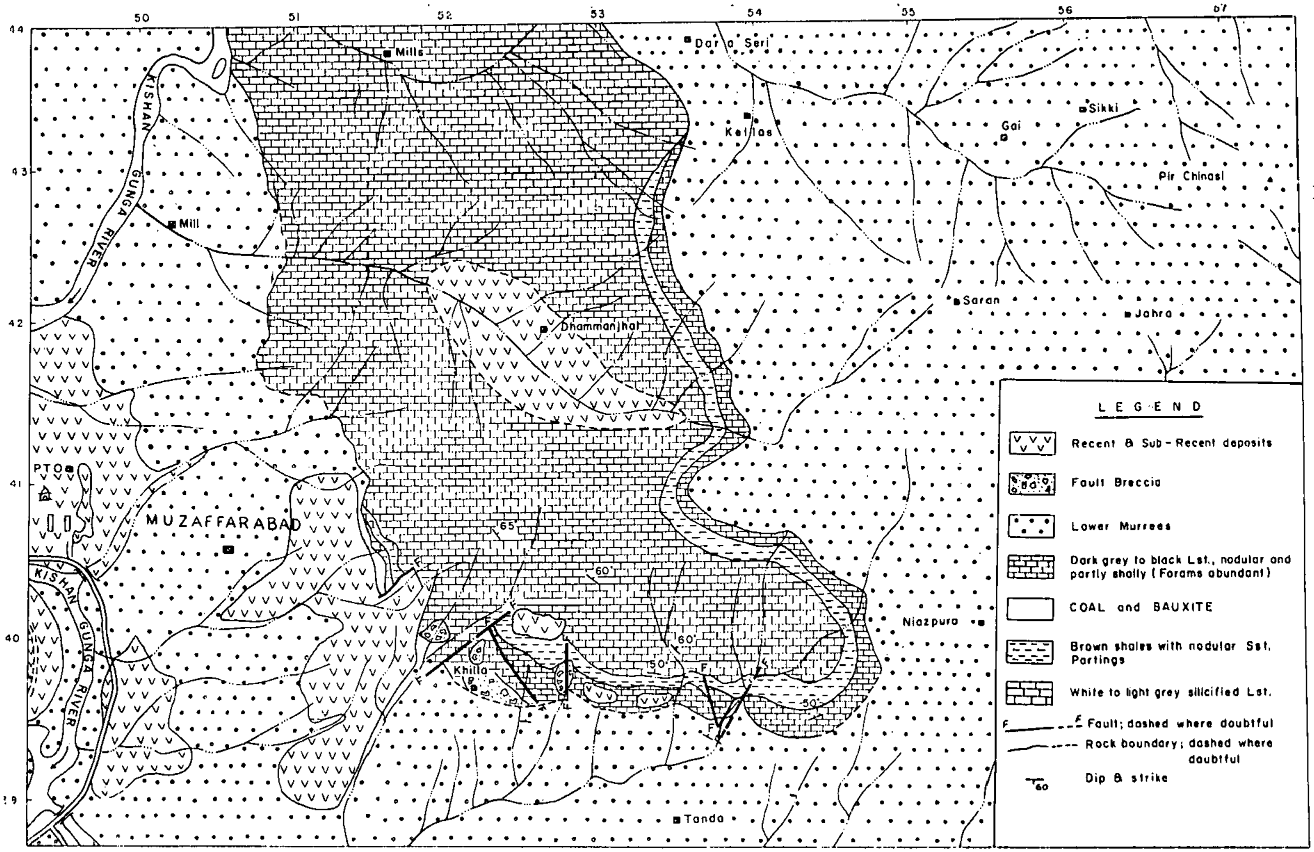

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FIG. I GEOLOGY AND MINERAL RESOURCES OF MUZAFFARABAD AREA AZAD KASHMIR

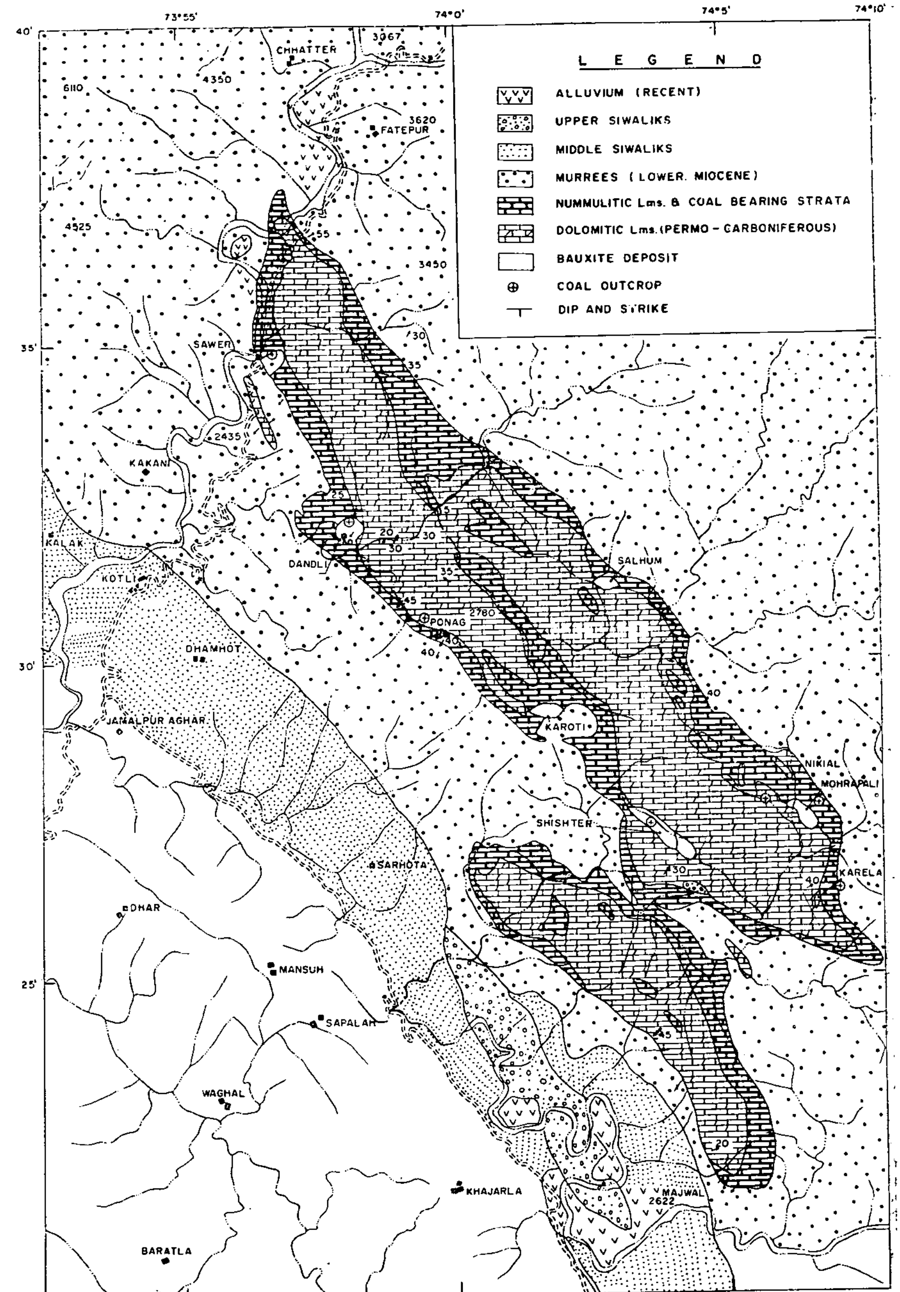

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FIG. 2 GEOLOGY & MINERAL RESOURCES OF KOTLI TEHSIL, MIRPUR DISRICT, AZAD KASHMIR.

Above the limestone is the thinly bedded dark gray to black, compact and brittle dolomite.

Precipitation breccia stands out in relief on the top of the dolomite and contains disseminated lath like grains of quartz.

The fire clay and the bauxite overlie the Muzaffarabad Formation of Permo-Carboniferous age. The bauxite is light to dark gray, gray, yellow, brown and dirty white in color and occurs in small pockets and lenses in association with the basal bed of gray and dark gray fire clay. The top of the bauxite bed is pisolitic and grades into non-pisolitic variety at the bottom. Average thickness of the pisolitic bauxite is 2.5 feet and that of the underlying fire clay is 5—10 ft.

At some places the pisolitic bauxite has been completely eroded and only the poorly pisolitic part at the bottom is exposed.

The Chhalpani Formation of Eocene age overlies the bauxite and is a continuous belt of rocks of varying thickness in all the areas of Muzaffarabad and Kotli Tehsil. It is composed of dark carbonaceous light gray to olive and yellowish color calcareous shales; light gray medium grained sandstone; and dark gray to almost black nummulitic limestone. The dark carbonaceous shale above the pisolitic bauxite contains the coal.

METHOD AND MATERIAL

Two localities from Muzaffarabad area and five localities from Kotli Tehsil area as mentioned earlier were selected for sampling of the bauxite and the associated underlying and overlying rocks of Permo-Carboniferous and Eocene ages respectively.

The samples were collected by digging pits of different depths in the bauxite and the associated beds of the localities under study. The samples collected represent the rocks and the bauxite right from the top of Muzaffarabad Formation to the Eocene shales interbedded with limestone, overlying the pisolitic bauxite. Besides, the samples were also collected at various horizons of a bed. Physical differences in color, texture, structure and the thickness of a particular bed were important considerations during the collection of the samples. To facilitate the study of the degree of correspondence between the beds, special consideration was given to the samples collected from the contact zones of the beds.

Few samples have also been collected from the dolomite bed to determine the degree of correspondence, if any, between the dolomite and the overlying precipitation breccia of the same age.

MICROSCOPIC STUDY OF NON CLAY MINERALS IN THE BAUXITE AND THE ASSOCIATED ROCKS

The texture of the bauxite limits the microscopic examination of the minerals present in most of the ores. The feldspars, the amphiboles and pyroxenes are not present in fresh state, but they can be seen in their altered conditions. The feldspars occur as kaolinized and sericitized grains. The amphiboles and pyroxenes show alteration to biotite, epidote and small specks of iron oxide.

Banded algal structures are quite pronounced and conspicuous in the fire clay and the non-pisolitic portions of the bauxites.

The thin sections of the samples of the bauxite and the associated rocks from seven different localities of Muzaffarabad and Kotli Tehsil of Azad Kashmir were examined to study the local variations in the shape, mineralogy, and stability of the mineral grains in the bauxite and the associated beds. Special attention was paid to the study of similar and dissimilar minerals in the bauxite bed in relation to the underlying Muzaffarabad Dolomite and the precipitation breccia. The overlying Eocene Formation which consists of interbedded shale and limestone was also examined megascopically and microscopically to determine the degree of correspondence of the bauxite with them. Special emphasis was given to the study of the samples collected from the contact of the two consecutive beds to facilitate the study of mineralogical transition or intermixing, if they were laid down in the same cycle of deposition with some degree of fluctuations in the depositional basin.

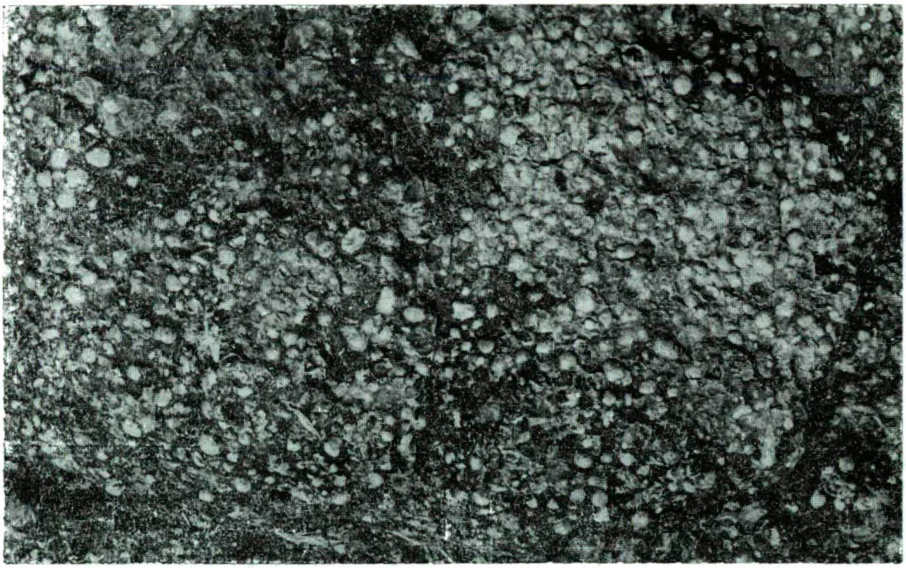
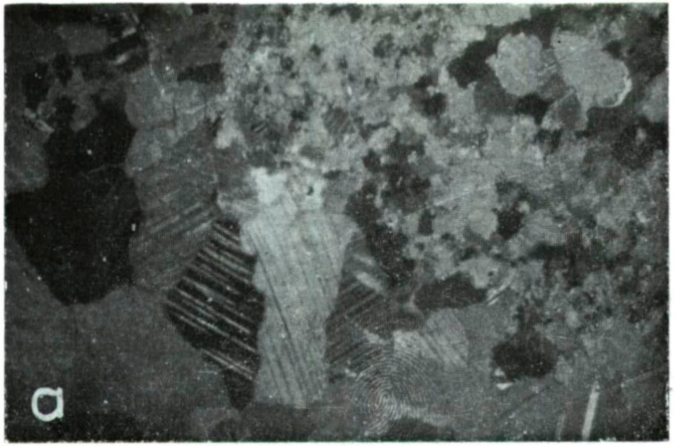
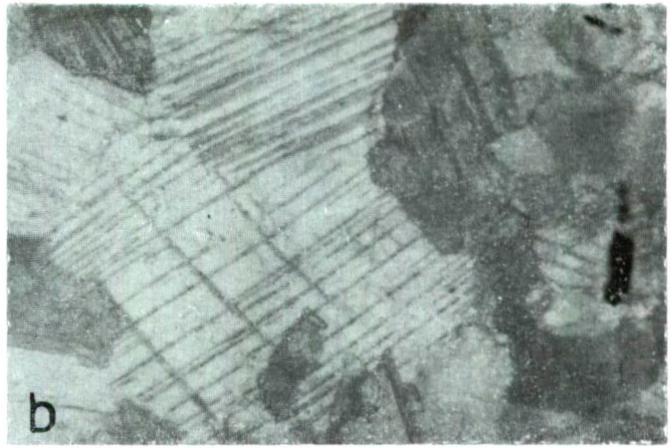


Fig. 3. Photograph showing the texture of the pisolitic bauxite in Salhun locality of Kotli Tehsil

The identification of non-clay minerals in the underlying Muzaffarabad Formation and the Eocene Formation which overlies the bauxite bed was not so difficult as the study of the minerals in the samples of the fire clay and the bauxites of all the selected localities under present investigation. The difficulty in identification of non-clay minerals in the fire clay and the bauxite bed was due to their higher degree of decomposition. The decomposition took place during the deposition of the fire clay and the bauxitization process. Diagenetic minerals such as kaolinite, biotite, epidotc and iron oxide specks are quite pronounced and occur in association with the parent minerals like feldspar and amphiboles respectively and can easily be studied in thin sections of the fire clay and the bauxites *(Figs. 7* to *9)*.

In megascopic study the Muzaffarabad Dolomite appears as light gray to dull white. The texture is fine to medium grained. The aggregate of fine grains gives an appearance of sugary texture and can easily be seen without the aid of a magnifying lens. The structure is compact and the rock appears brittle when hammered. The thin sections of the dolomite show clustering of grains which is usually more pronounced in the coarser grains of the rocks. However, the clustering of finer





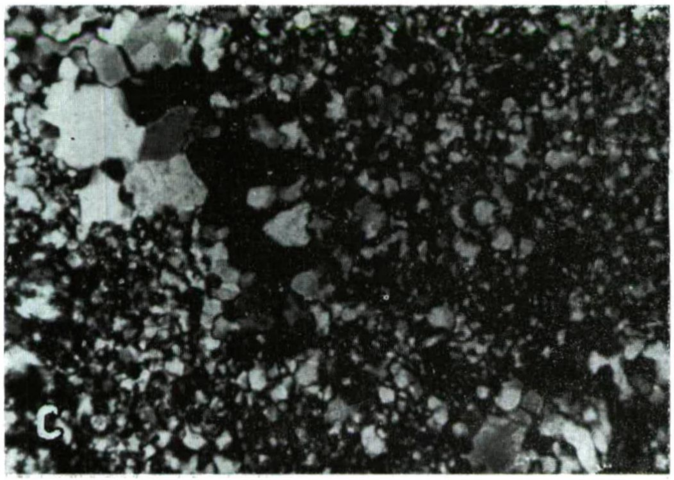


Fig. 4. a) Fine to coarse grained aggregate of anhedral crystals of dolomite from Khander, Kotli area with twinning lamellae in larger crystals only. x50.4, crossed polarizers. *b)* Anhedral crystals of dolomite with twinning lamellae and rhombohedral cleavage from Khandar, Kotli area. 50.4x, crossed polarizers. *c)* An aggregate of fine to coarse anhedral crystals of quartz in precipitation breccia from Khilla, Muzaffarabad area. x50.4, crossed polarizers

grains is also observed *(Fig. 4a)*. The grains of the dolomite appear as an aggregate of medium to coarse grains and exhibit granular texture. The cementing material between the grains is scanty and the grains lie in random orientations. Conspicuous partings and cleavage directions *(Fig. 4b)* are present. In some of the grains rhombic cleavages are quite pronounced. It appears that the dolomite is a product of interaction between the limestone and the sea water ladden with magnesium ions. Some grains of black opaque specks probably of iron oxide are also present.

The precipitation breccia forms the top of the Muzaffarabad Formation in nearly all the areas of Muzaffarabad and Kotli Tehsil of Azad Kashmir. The thickness of the precipitation breccia varies from one locality to another but no variation in mineralogy, texture and structure has been noted.

Megascopically the precipitation breccia is light gray to white. The main body of the sample shows fine grained texture but laths of chert up to two centimeters in size embedded in fine grained aggregates of the same material are common. With the aid of a magnifying lens the grains appear angular to subangular in their shape and are lithified very coherently and so the rock appears compact in its structure. In thin sections the grains of quartz appear to dominate the rock body. The cementing material between the grains is very scanty and the texture is quartzitic *(Fig. 4c)*. Few grains of orthoclase and albite showing kaolinization and sericitization effects were also found.

At Khander lateritic patches lie between the precipitation breccia and the fire clay. The laterite is reddish brown to dark brown in color and exhibits coarse to medium grained texture. No minerals could be identified in the hand specimens due to coatings of iron oxide on the grains.

The thin sections of the samples of laterite show the dominance of orthoclase and albite grains embedded in ferruginous matrix. Some grains of plagioclase and quartz were also found but they are not very common. Usually the grains of feldspars are angular to subangular in their shapes. Most of the grains are kaolinized and sericitized along the margins and cracks but the degree of alteration in feldspar grains of the lateritic patches is much less as compared to the same mineral in the fire clay and the bauxite bed *(Figs. 6, 7)*. Some of the larger grains of feldspars present in thin section of laterite samples *(Fig. 5a, d)* are showing kaolinization effect very conspicuously due to diagenesis.

The color of the fire clay ranges from black to brown and various light and dark shades between these two colors. The texture is fine grained and the structure is compact. The thickness of the bed varies from 3 to 6 feet. Few pisolites were also found in the fire clay. Due to fine grained texture and argillaceous nature of the rock the identification of minerals in the hand specimen is not possible.

The study of the thin sections of the rocks shows the presence of the grains of quartz, kaolinized and sericitized albite and orthoclase embedded in blackish brown argillaceous matrix. Few grains of ferro-magnesian minerals of pyroxene and amphibole groups were also found in altered conditions. The alteration product of these minerals is biotite, epidote and some clay minerals which appear dirty white and cloudy in thin sections. *(Fig. 6d.)* Flakes of biotite, few grains of apatite, anatase and epidote were also seen under the microscope. Exact identification of the mafic minerals is not possible due to intense decomposition of the mineral grains. However, their outline, the development of cracks and the black specks of iron oxide in the body of the grains are quite pronounced. Calcite and muscovite are common. Small specks of iron oxides with random distribution are of common occurrence in the main body of the rock. In all the samples of fire clays from the

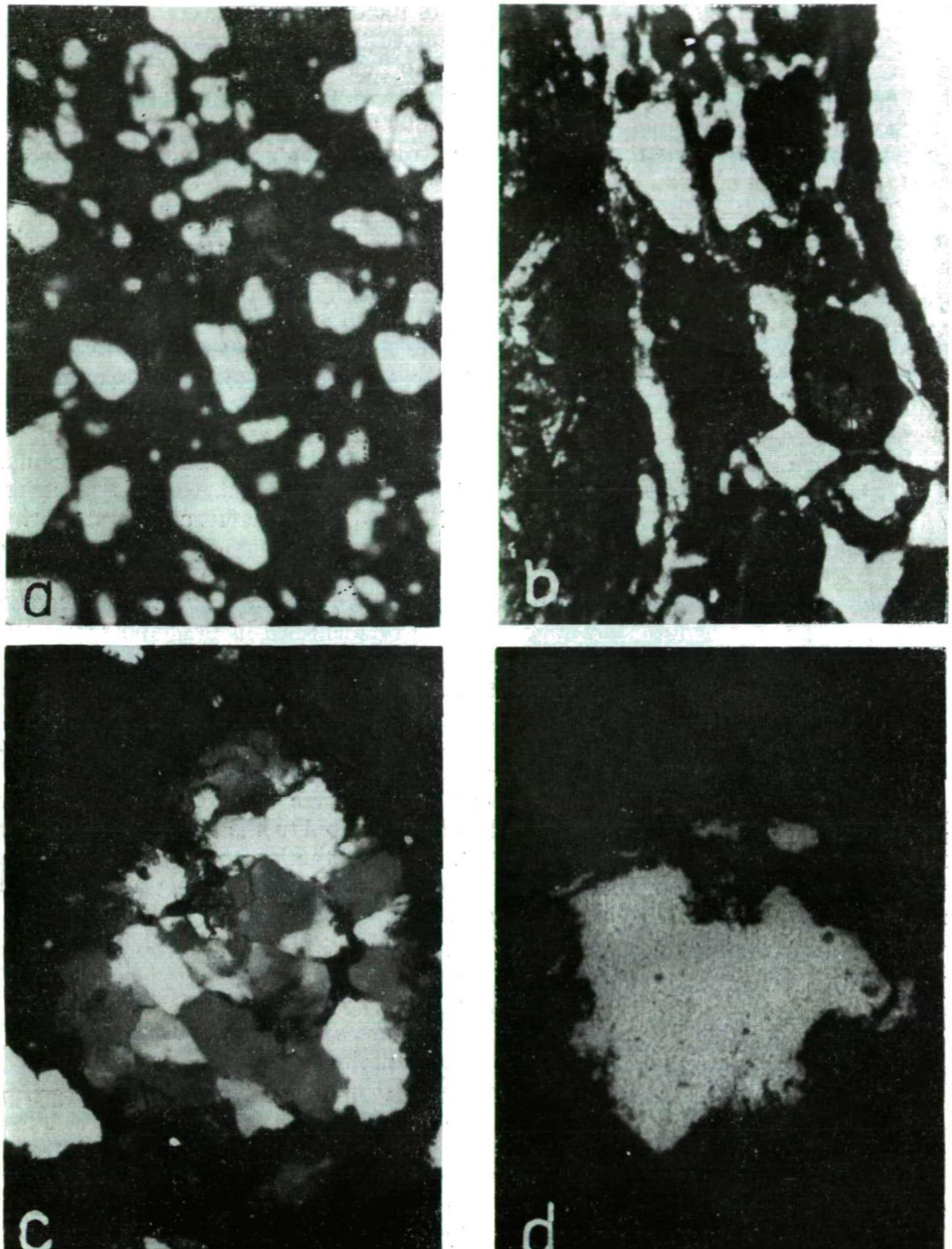


Fig. 5. a) Anhedral kaolinized grains of feldspar embedded in lateritic matrix from Khander, Kotli area. x50,4, polarized light. *b)* Less altered angular to subangular grains of feldspar embedded in lateritic matrix from Khander, Kotli area. x50.4, polarized light. *c)* An aggregate of feldspars and quartz grains surrounded by lateritic matrix from Khander, Kotli area. x50.4, crossed polarizers. *d)* A grain of feldspar surrounded by lateritic matrix from Khander, Kotli area, is kaolinized and angular in shape, x50,4, polarized light.

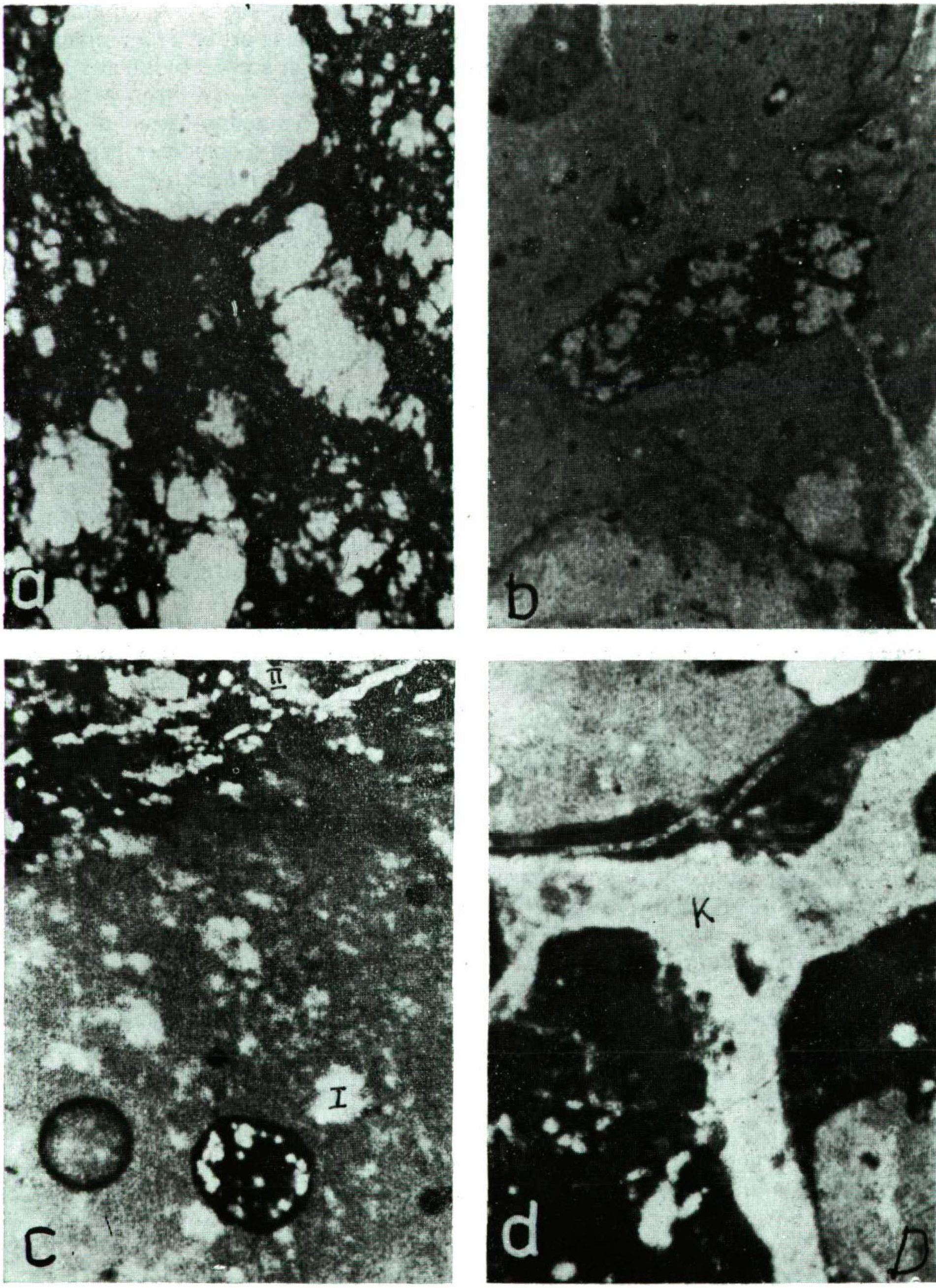


Fig. 6. a) Kaolinized feldspars in the fire clay from Salhun, Kotli area. x50.4, polarized light. *b)* Altered amphibole grain in the fire clay, from Khander, Kotli area. x50.4, polarized light. *c)* Pisolite and decomposed feldspar grains embedded in the fire clay from Nikial, Kotli area. 50.4x, polarized light. *d)* Decomposed feldspar grains and clays (k) filling the cracks in the fire clay from Khilla, Muzaffarabad area. x50.4, polarized light.

various localities of Muzaffarabad and Kotli Tehsil, banded structure is quite common and well pronounced *(Fig. 7a, b)*. The banded structure is probably an indication of the transportation of algal material along with the argillaceous sediments in the basin of deposition. It is also possible that the algal material had been present in the basin of deposition and so when the transported sediments came in contact with the algal materials, both were deposited together and formed the bed of the fire clay. The banded structure in the fire clay resembles much the structure usually found in the algal limestone and so it is possible that the conditions during the deposition of the fire clay were the same as required for the deposition of the algal limestone.

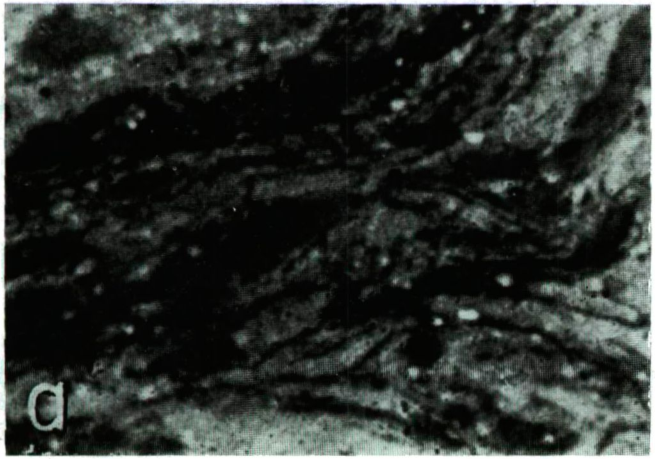
Megascopically the color of the bauxite samples ranges from black to light gray and various light and dark shades between the two colors. The pisolites in the bauxites range from 5 mm to 3 cm in diameter. The pisolites are more abundant at the top of the bed than at the bottom which is in contact with the top of the fire clay. The aggregate of smaller pisolites is not very tightly cemented and they can be seperated if pressed with the thumb. This property of friability is not common in case of those samples which contain larger pisolites but they are more firmly cemented and compact. The size of the pisolites and their color differ from one locality to another. Usually the pisolites in the bauxite samples of Batmong and Khilla localities of Muzaffarabad area are 2—8 mm in diameter and are less compact than the pisolites of the bauxite samples of various localities of Kotli area which range from 2 mm to more than 5 cm in diameter.

The thin sections of the bauxite samples show the presence of argillaceous and ferruginous matrix in which grains of orthoclase, albite, quartz, flakes of muscovite and biotite, are embedded. Few grains of anatase, apatite and calcite were also found. Specks of iron oxides were also seen under the microscope.

The grains of albite and orthoclase are angular to subangular in shape. These mineral grains are kaolinized and sericitized though their outlines are quite prominent. Generally in thin sections of the pisolites the mineral grains show their outlines quite conspicuously, but in some cases the grains are so intensely decomposed that the study of the shape is difficult *(Fig. 9)*. The internal structure of the pisoitesl commonly shows concentric character in all the localities under present investigation. In some of the pisolites few laths of feldspars appear as trapped grains in carbonaceous and argillaceous matrix. In others the rim is lined by altered grains of feldspars, and the internal material is carbonaceous to argillaceous with few grains of decomposed feldspar. In such pisolites the pisolitic structure is not well developed. Some of them exhibit random setting of non-clay mineral grains specially feldspars in them. It appears from the study of the internal structure of the pisolites that the local disturbances in the environment of bauxitization and pisolite formation were active and caused irregularities in the internal structure and setting of the mineral grains in them. Probably the disturbance in the supply of organic matter and the sediments were more intense at the time of bauxitization.

In non-pisolitic bauxite samples also some grains of feldspar and other minerals mentioned above are present, exhibiting the same degree of decomposition of the mineral grains as in the pisolites. In some cases the altered feldspars appear to dominate over the matrix *(Fig. 8b)*.

The matrix of the Eocene shale is argillo-ferruginous and appears as gray to grayish white in color. The mineral grains studied in the thin sections of the shale samples are angular to sub-angular orthoclase, albite, quartz, muscovite, biotite and specks of iron oxide in order of their abundance. The grains of orthoclase and



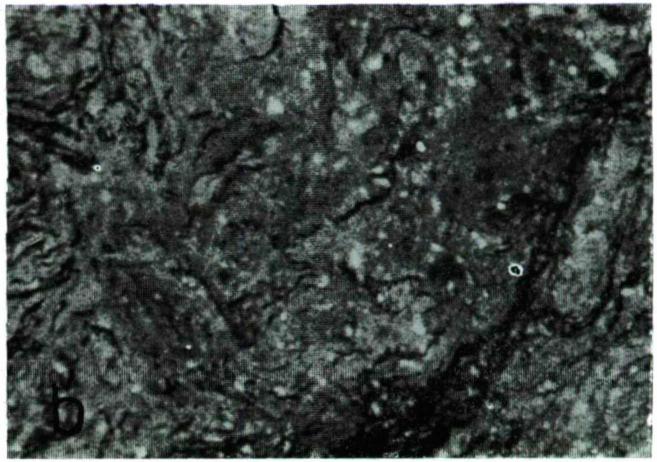
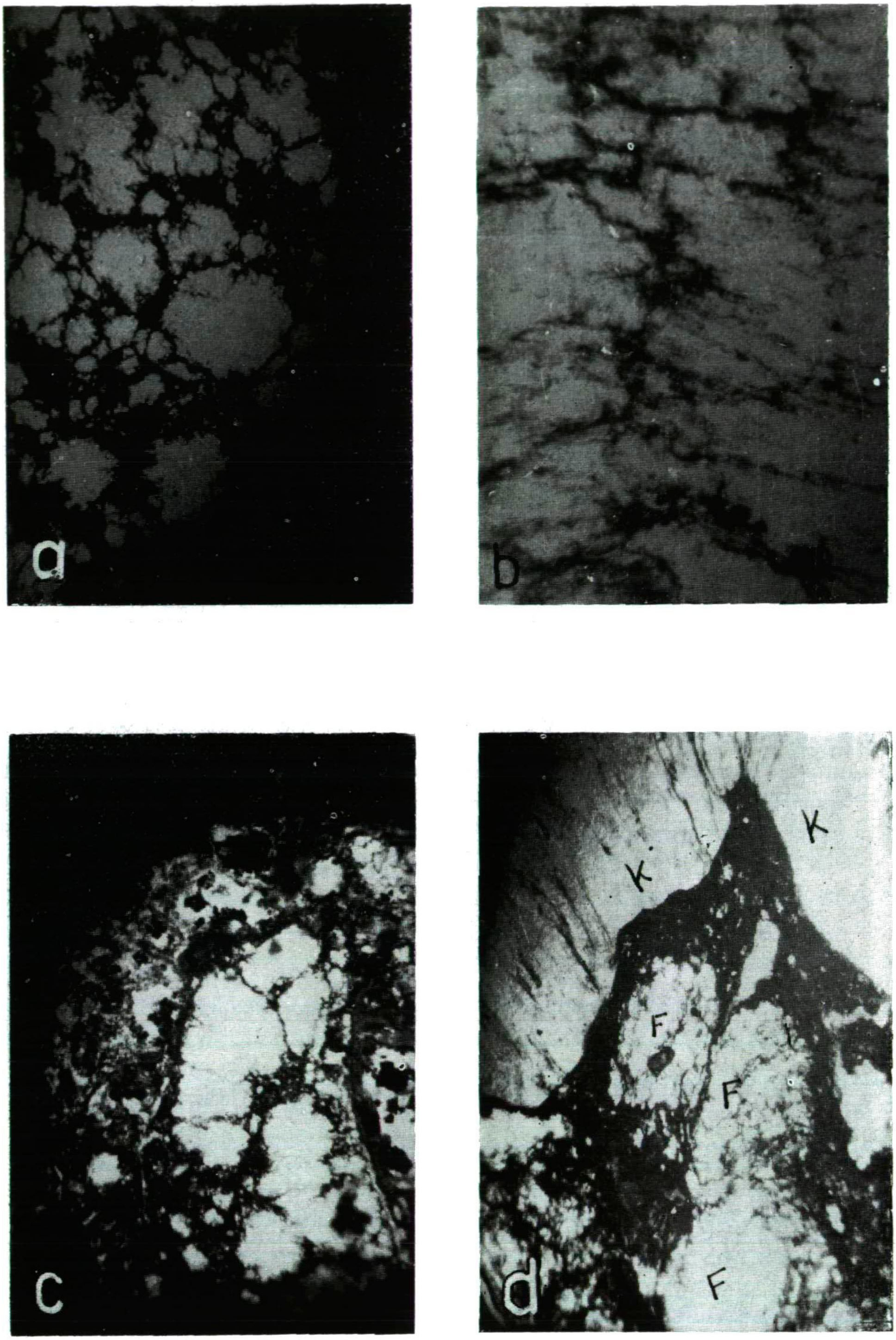


Fig. 7. a) Banded algal structure with fine grains of kaolinized feldspars in the fire clay from Khander, Kotli area. x50.4, polarized light. *b)* Closely banded algal structures with white spots of kaolinized feldspars in the fire clay from Khander, Kotli area. x50.4, polarized light. *c)* Decomposed feldspars grains are embedded in the fire clay of Khander, Kotli area. x50.4, polarized light.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albite are kaolinized and sericitized but the decomposition of the grains is not as intense as in the samples of the bauxite and the fire clay. Kaolinization and sericitization are more conspicuous along the margins, cleavages and cracks, than on the main surface of the grains. Micrites and calcite grains are quite conspicuous and common.

DISCUSSION

The textural and mineralogical study of the samples in thin sections indicate dolomitization of the limestone which forms the base of Muzaffarabad Formation. It seems that prior to the deposition of precipitation breccia dolomitization of Muzaffarabad limestone was completed in the shallow marine environment which usually has a higher concentration of magnesium than the deep water of the sea [FAIRBRIDGE, 1963]. The dolomite because of its higher effective porosity as compared to the limestone allowed the siliceous solution to percolate through to the limestone at the base and fill the cavities present in it. Precipitation breccia veins and cavity fillings are also found in the dolomite, but they are not as common as in the limestone.

If it is supposed that deposition of the precipitation breccia was simultaneous with the dolomitization, then it becomes difficult to explain the presence of precipitation breccia in the cavities of Muzaffarabad Limestone.

The precipitation breccia is referred to either as silicified limestone [MASTER, 1957]; or lime breccia [G. M. C., 1965] or chert breccia [MR. S. H. FAROOQI, Pakistan Indust. Develop. Corp., personal communication, 1970]. The present study which is based on megascopic and microscopic identification of minerals in thin sections indicates that this bed is the result of siliceous precipitate. This conclusion is also supported by the differential thermal analysis data and the chemical analyses of the samples which show 95% SiO_2 contents [MALLICK and VALIULLAH, 1971]. The similarity of the texture to the breccia is because of recrystallization and diagenesis. The precipitation from solution is also proved by its presence as cavity fillings in the Muzaffarabad Limestone as mentioned above. It therefore, appears appropriate to name this rock as precipitation breccia.

The presence of altered angular to subangular grains of feldspars, ferromagnesian minerals probably of amphibole group, the quartz grains in the argillaceous matrix of the fire clay and the pisolitic bauxite reveal their transported nature and a common source. The presence of lateritic patches containing comparatively fresher grains of minerals than in the fire clay and the pisolitic bauxite, and its position between them further indicate immature state of the material which formed the two beds.

The negative correspondence of the fire clay and the pisolitic bauxite with the associated underlying Muzaffarabad Formation and the overlying Eocene Formation is clearly indicated by the microscopic examination of the minerals in thin sections.

Fig. 8. a) Non-pisolitic bauxite from Nikial, Kotli area, with abundant fresh feldspar grains. 50.4x, polarized light. *b)* Non-pisolitic bauxite from Nikial, Kotli area, showing kaolinized feldspar grains in argillaceous matrix. 50.4x, polarized light. *c)* A part of the poorly developed pisolite from Batmong, Muzaffarabad area showing fine to coarse grains of feldspar trapped in it. x50.4, polarized light. *d)* Non-pisolitic bauxite from Khilla, Muzaffarabad area, showing kaolinized feldspar grains and some completely kaolinized feldspar (K). trapped in argillaceous matrix. x50.4; polarized light.

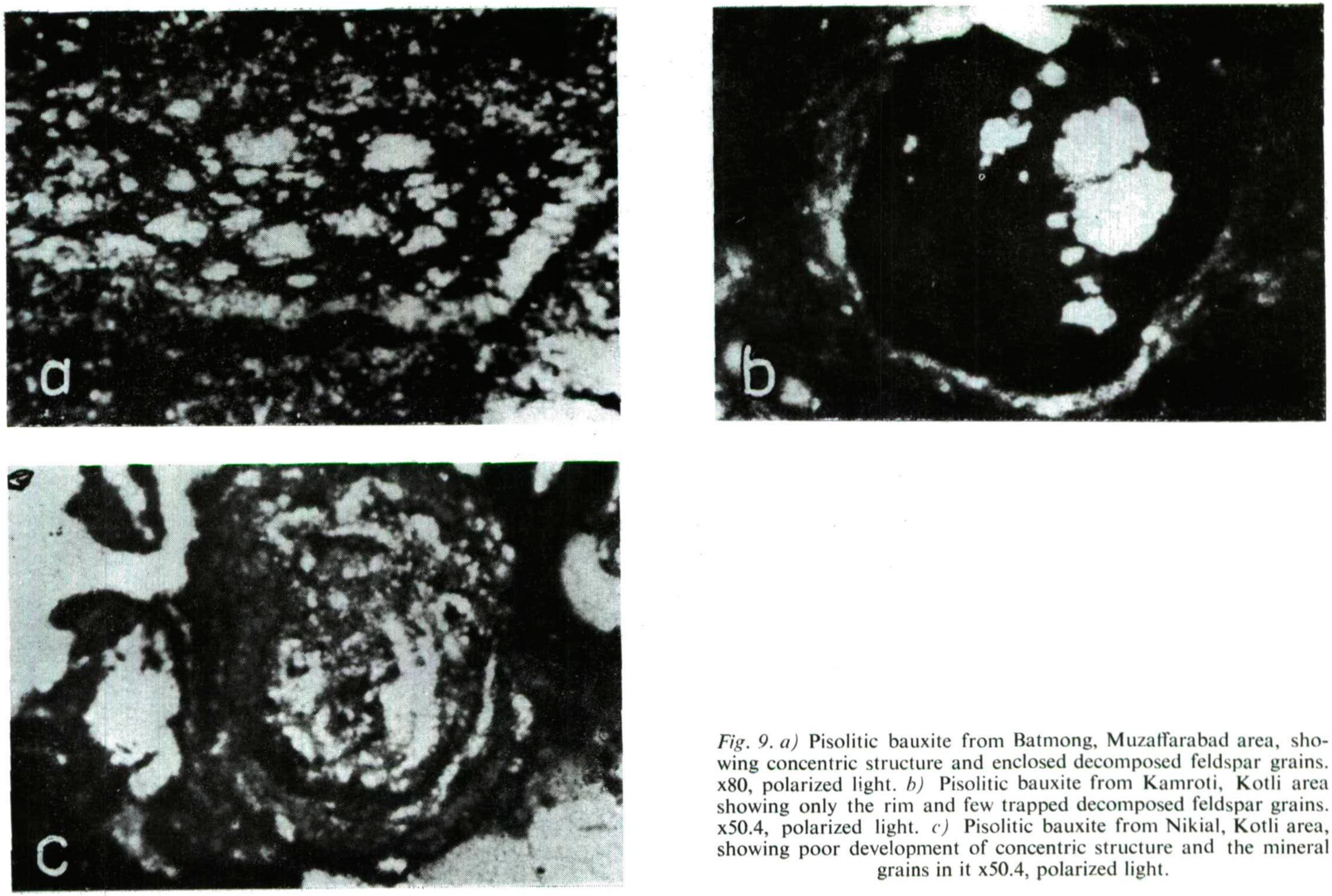

Fig. 9. a) Pisolitic bauxite from Batmong, Muzaffarabad area, showing concentric structure and enclosed decomposed feldspar grains. x80, polarized light. *b)* Pisolitic bauxite from Kamroti, Kotli area showing only the rim and few trapped decomposed feldspar grains. x50.4, polarized light. *c)* Pisolitic bauxite from Nikial, Kotli area, showing poor development of concentric structure and the mineral grains in it x50.4, polarized light.

The provenance of the fire clay and the pisolitic bauxite was most probably in the north and north east of Muzaffarabad trough which is occupied by the gneisses, schists, slates and the early Tertiary intrusions of granite, syenite, granodiorite and diorite.

The positive correspondence between the fire clay and the pisolitic bauxite, on the basis of their mineral assemblage is probably due to their common provenance. The cycle of deposition also appears to be the same with some fluctuations in sedimentation and shallowing of the depositional basin when the pisolitic bauxite was in the process of formation.

While studying the bauxites from Jammu province ASHOK [1967] concluded that the provenance of the bauxites is in Pir Panjal trap which is situated further north from the localities of the bauxite deposits. But the present study reveals that the source rocks of Azad Kashmir bauxites are the alkaline igneous and metamorphic rocks as mentioned above and is discussed below:

GEE [1957] is of the opinion that the basin structure of West Pakistan was emerging from the north and was submerging in the south during Mesozoic and Tertiary times. This statement further supports the possibilities of the source rocks for the fire clay and the bauxite deposits to be in the north.

The algal structure as seen in the thin sections of the fire clay and the bauxites *(Fig. 7)* is an indication of vegetation at the time of deposition of the two beds which would have been a cause of higher percentage of silica in the deposits.

The dominance of feldspar grains in the fire clay and the bauxite samples as compared to silica is probably because of the dominance of alkaline rocks in the provenance.

LOUGHNAN and BAYLISS [1961] described a large deposit of bauxite near Weipa, Queensland, Australia which formed from quartzose rocks containing less than 4% alumina.

The fire clay and the bauxites of Muzaffarabad and Kotli Tehsil do not show any degree of positive correspondence with the immediate underlying precipitation breccia of Muzaffarabad Formation with respect to the clay and non-clay minerals which are identifiable in the bauxite and the fire clay. Therefore, it is unlikely, at least in the area of the present study that the origin of the fire clay and the pisolitic bauxite is from the precipitation breccia of Muzaffarabad Formation, as suggested by Loughnan and Bayliss for the origin of Weipa bauxite of Queensland from quartzose rocks.

The desilicification of the overlying Eocene beds responsible for the origin of the precipitation breccia (previously called as silicified limestone) as suggested by MASTER [1958], does not seem very reasonable in the light of the present observations and their interpretations as discussed above. However, with the help of the available informations on clay formations and its age relationships and because silica precipitates in acidic environment, it is concluded that acidic oxidizing environments were present at the time of deposition of the precipitation breccia, the fire clay and the bauxites. The sutured texture present in the precipitation breccia may be attributed to the recrystallization and diagenesis of the siliceous precipitate.

CONCLUSIONS

1. The chert breccia should more appropriately be termed as precipitation breccia.
2. The precipitation breccia is a chemical precipitate with no change in the mineral composition from one locality to another and is not related to the bed below it.

3. Texture of the precipitation breccia is the result of diagenetic processes and recrystallization.
4. Dolomitization of Muzaffarabad Limestone took place prior to the deposition of the precipitation breccia on its top.
5. The fire-clay and the overlying pisolitic bauxite show mineralogical similarities.
6. The mineralogical similarities and undulatory contact between the top of the fire clay and the bottom of the bauxites which grades upward into highly pisolitic bauxite indicate same cycle of their deposition. Most probably shallower and agitating water environment was prevailing when the pisolitic bauxite was being deposited.
7. The bauxite and the fire clay are detrital in origin and have common parentage in alkaline igneous and metamorphic rocks exposed in the north and northeast of Muzaffarabad Trough.
8. The bauxite is immature with respect to alteration of its non-clay minerals.

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Dr. K. A. Mallick
Dr. M. Valiullah
Department of Geology,
University of Karachi
University Road, Karachi-32, India